

# Characterization of Dominant Benthic Diatoms in Some Rivers of Bamenda (North-West Region, Cameroon)

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## ABSTRACT

**Aims:** Diatoms have been extensively studied by ecologists and taxonomists. They are used for monitoring water quality. Human activities more and more deteriorate the quality of rivers of the city of Bamenda due to rural exodus caused by the social crisis in the North-West Region in Cameroon. The objective of the study was to characterized benthic diatoms in some Rivers of Bamenda with the aim of restoring and monitoring them.

**Study design:** Diatoms are used for monitoring water quality.

**Place and Duration of Study:** Study took place from January to December 2023 in the city of Bamenda.

**Methodology:** Sampling of Diatoms was done by scrubbing macrophytes for periphyton and scrapping rocks for epilithon. Some physicochemical parameters of water in the study sites were measured.

**Results:** Results showed that 44 abundant and dominant species were identified. *Caloneis bacillum*, *Cymbella gamma*, *Pinnularia gibba*, *Melosira varians* and *Aulacoseira granulata* were frequent with the relative frequency located between 81 to 100%. Majority of genera were cosmopolitan and tolerated high level of salinity and nitrates.

**Conclusion:** Some Diatoms species identified in the study area are resistant to pollution and others sensitive, and could be used for developing biological diatom indices. They could be proposed to local council and government for managing water from rivers.

**Keywords:** Benthic diatoms, Characterization, Physicochemical parameters, Rivers, Relative frequency.

## 1. INTRODUCTION

Diatoms are photosynthetic algae; they have a siliceous skeleton (frustule) and are found in almost every aquatic environment including fresh and marine waters, soils, in fact almost anywhere moist. They are non-motile, or capable of only limited movement along a substrate by secretion of mucilaginous material along a slit-like groove or channel called a raphe. Being autotrophic they are restricted to the photic zone. Both benthic and planktonic forms exist. Diatoms are formally classified as belonging to the Division Chrysophyta. The Chrysophyta are algae which form endoplasmic cysts, store oils rather than starch, possess a bipartite cell wall and secrete silica at some stage of their life cycle. Diatoms are commonly between 20-200 microns in diameter or length, although sometimes they can be up to 2 millimeters long. The cell may be solitary or colonial (attached by mucous filaments or by bands into long chains). Benthic diatoms are microalgae used wide world for water quality assessment. Diatoms are microscopic, unicellular organisms that have a cell wall made up of silicon dioxide (Mann and Vanormelingen, 2013; Shibabaw et al., 2021).

Diatoms are able to photosynthesize; they convert dissolved carbon dioxide in water into oxygen. Diatoms can play an important role in the energy and nutrient cycles of water resources (Beraldi-Campesi et al., 2016). They are the primary food source for higher organisms in the food chain such as invertebrates and fish. Diatoms may occur in such large numbers and be well preserved enough to form sediments composed almost entirely of diatom frustules (diatomites), these deposits are of economic benefit being used in filters, paints, toothpaste, and many other applications (Field et al., 1998; Armbrust, 2009).

Diatoms have been studied since the late eighteenth century; however the first real advances in the field came in the early nineteenth century when diatoms were popular with microscopists utilizing the emerging improvements in microscope resolution (OFEV, 2007; Vélez-Agudelo and Espinosa, 2021). Several European workers produced hand illustrated monographs on diatoms in the late nineteenth century. Notable amongst these are the works of Cleve, Ehrenberg, Grunow, Schmidt and Van Heurck. In the early twentieth century fossil diatoms were first studied and, most famously, Hustedt (1927-66) produced a taxonomic and ecological study of diatoms which remains a key reference today.

Cameroon has an important hydrographic network like the city of Bamenda (Ndikebeng et al., 2023). However, urban expansion, rampant and spontaneous anthropization lead to increase pollution, imbalance and reduction of wetlands. With a view to restoring degraded hydrosystems as well as establishing ecological monitoring measures, it is imperative to have a national diatomic database. To do this, extensive sampling and analysis campaigns should be carried out to be able to characterize the species on a regional and national scale. It is with this in mind that it is a question of making an inventory of the benthic flora and describing some of the main genera of diatoms populating the rivers.

## **2. MATERIAL AND METHODS**

### **2.1. Description of study area**

Bamenda (5°56' - 6°00' N and 10°08' - 10°12' E) is the head quarter of Mezam division in the North-West Region of Cameroon (Fig. 1). It is made of three subdivisions (Bamenda I, Bamenda II and Bamenda III) with 391 km<sup>2</sup> as total surface area. Its relief consists of interspersed plateaus with deep valleys. Its vegetation is the Guinea Savannah type with moderate temperatures. There are two topographic units separated by a high scarp-oriented NE-SW (Neba, 1999). Above the cliff, stands the upper plateau which is mainly Bamenda I and represents 10% of the total area of the city. Altitudes here vary between 1472 m and 1573 m. The climate is the type of humid tropical highland characterized by two seasons: rainy and dry. The temperature here is very cold especially in the morning and evening with the coldest temperature between the periods of January to March with minimum temperature from 14.1 °C to 17.8 °C and maximum temperature from 22.5 °C to 28.5 °C, humidity ranging from 39% to 90% and rainfall from 0.1 to 14.1 inches of rain per hour. The rainy season is generally longer and lasts for 8 months (mid-March to mid-October) with a short dry season of 4 months (mid-October to mid-March) (Tita et al., 2012). The town has a rich hydrographical network with intense human activities and high population along the different watercourses in the watershed (Neba, 1999).

In Bamenda Town (North-west, Cameroon), major wetlands occur along the Mezam River floodplains and its tributaries especially in Ngomgham, Mulang, Ntenefer, Below Foncha, and Mile 4 Nkwen. The lawless occupation of wetlands has intensified recently due to demographic pressure as soils in these areas are very fertile and support year-round market gardening. Some human activities in these wetlands (land reclamation, waste disposal, deforestation, agriculture, industrialization, etc.) have led to the degradation of most of these ecosystems (Nyambod, 2010).

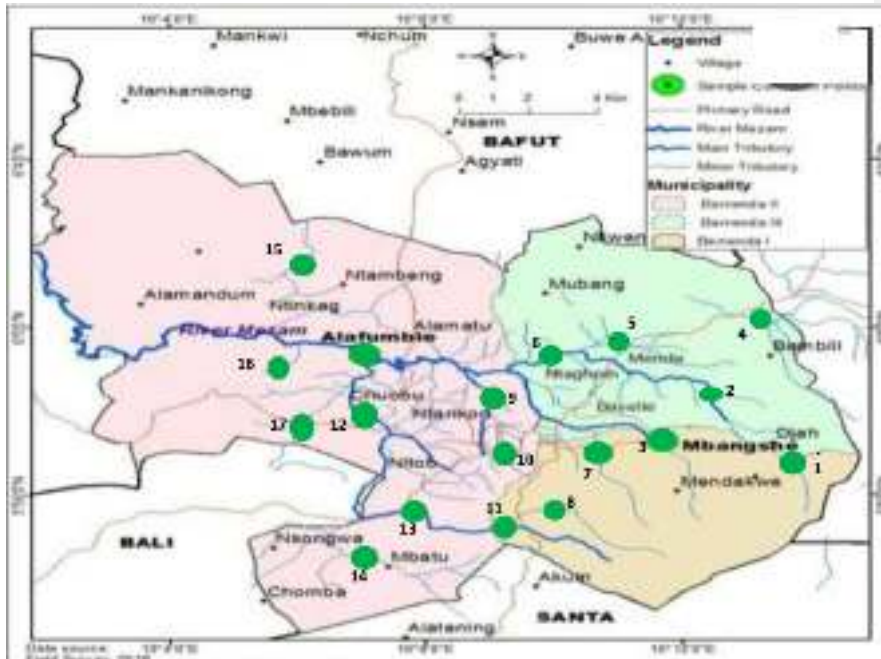


Figure 1. Localization of study sites (Ndikebeng et al., 2023 modified).

## 2.2. Sampling of Diatoms

Study took place from January 2023 to December 2024 in the city of Bamenda. The sampling was done in 17 sites along the Mezam wetlands in Bamenda (Fig. 1). In the study sites, a surface of  $30 \times 30 \text{ cm}^2$  was delimited on the rock sides exposed to the water, scraped and residues were transferred in the 150 ml. A surface of  $30 \times 30 \text{ cm}^2$  was delimited on macrophytes bound in the water; macrophytes in this surface are detached and squeezed. The residues were transferred in the 150 ml bottle. Ten (10%) of formalin was fixed in the sample for preservation. All the samples were transferred to the laboratory of Plant Biology of The University of Douala for analyses.

## 2.3. Preparation of samples in the laboratory

Subsamples were taken after homogenization and diluted with distilled water. The coverslips were placed at regular distances on the hot plate. After stirring, 0.5 ml of the contents of the subsample was placed on the coverslips and heated until evaporation. After drying the material, the temperature was increased to carbonize the organic matter until it turned grey. The coverslips were immersed in distilled water to remove ash. Several preparations were thus carried out with different dilutions.

## 2.4. Analysis and identification of species

The preparation was mounted between slide and coverslip. This microscopic work includes determining the species and counting the valves of diatoms, such as the small ornamentations of the valves. The following identification keys were used: (Krammer and Lange-Bertalot, 1986; Camerilo et al., 1997; OFEV, 2007; Guiry and Guiry, 2024).

## **2.5. Counting of diatoms**

The counting was carried out according to the method of (OFEV, 2007). After determining the frequent diatoms in a sample, the counting of diatoms valves was carried out. At least 400 valves were counted. All valves found during enumeration have been identified. The counting was carried out on the entire preparation taking into account all the intact valves; whole cells were counted as 2 valves. Among the fragments, those with at least half a valve were counted.

## **2.6. Determination of biological parameters**

### **2.6.1. Frequency**

The absolute frequency of each species ( $F_a$ ) is equal to the total number of its occurrences in all the records. The relative frequency ( $F_r$ ) of a given plant species is defined as the ratio of its absolute frequency ( $F_a$ ) to the total number ( $N_r$ ) of surveys carried out on a given site. It results in the following expression:  $F_r = F_a/N_r$ ; this value is often expressed as a percentage:  $F_r (\%) = 100.F_a/N_r$ . The frequencies obtained were classified using the frequency class: 1-20% = I, 21-40% = II, 41-60% = III, 61-80% = IV, 81-100% = V.

### **2.6.2. Description of dominant genera**

During analyses, morphological characteristics, and measurements were taken for different identified species.

## **2.7. Determination of physicochemical parameters of study sites**

Some physicochemical parameters were measured between 8:00 and 11:00 a.m. in all the sites. Electrical conductivity, hydrogen potential, and salinity with a Temperature/pH/Salinity/Conductivity/TDS multi-parameter of OAKTON instruments Trademark. Some water samples were collected with polyethylene (PE) bottles of 1.5 L and stored at -5 °C, in darkness inside a cool box for the analysis of nitrates by using spectrophotometer methods in laboratory.

## **2.8. Statistical analysis**

Microsoft Office Excel software was used for keying and coding data collected during the study. Qualitative and quantitative variables were presented in tables.

## **3. RESULTS AND DISCUSSION**

### **3.1. Frequency of dominant species**

Relative frequency of dominant species varied from 100% to 16% in the study sites (Table 1). Relative frequency was high in the study sites with *Caloneis bacillum*, *Cymbella gamma*, *Pinnularia gibba*, *Pinnularia gibba*, *Melosira varians* and *Aulacoseira granulata* belonging in class V frequency.

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**Table 1. Floristic list of benthic diatoms in the study sites**

N/S	Species	RFr (%)	FrclZ
1	<i>Achnanthes exiguides</i>	16	I
2	<i>Achnanthes minutissima</i>	75	IV
3	<i>Achnanthes</i> sp.	25	II
4	<i>Achnanthidium linearis</i>	16	I
5	<i>Achnanthidium</i> sp.	33	II
6	<i>Planothidium lanceolatum</i>	33	II
7	<i>Caloneis bacillum</i>	83	V
8	<i>Caloneis placentula</i>	42	III
9	<i>Cocconeis pediculus</i>	16	I
10	<i>Cocconeis placentula</i>	33	II
11	<i>Cymbella frustule</i>	25	II
12	<i>Cymbella gamma</i>	92	V
13	<i>Cymbella kappi</i>	66	IV
14	<i>Cymbella mesodon</i>	25	II
15	<i>Cymbella naviculiformis</i>	25	II
16	<i>Cymbella</i> sp.	16	I
17	<i>Cymbella turgida</i>	16	I
18	<i>Cymbella ventricosa</i>	42	III
19	<i>Amphora ovalis</i>	25	II
20	<i>Diatoma mesodon</i>	25	II
21	<i>Diatoma sigma</i>	50	III
22	<i>Epithemia adnata</i>	33	II
23	<i>Gomphonema acuminatum</i>	42	III
24	<i>Gomphonema designatum</i>	42	III
25	<i>Gomphonema olivaceum</i>	33	II
26	<i>Gomphonema parvulum</i>	33	II
27	<i>Gomphonema</i> sp.	25	II
28	<i>Diatomella ballfouriana</i>	25	II
29	<i>Diatomella</i> sp.	16	I
30	<i>Pinnularia gibba</i>	100	V
31	<i>Pinnularia</i> sp.	33	II
32	<i>Diploneis eliptica</i>	50	III
33	<i>Navicula cryptocephala</i>	75	IV
34	<i>Navicula cuspidata</i>	33	II
35	<i>Fragilaria cruentus</i>	66	IV
36	<i>Fragilaria</i> sp.	33	II
37	<i>Gomphosphaerium</i> sp.	50	III
38	<i>Melosira</i> sp.	50	III
39	<i>Melosira varians</i>	100	V
40	<i>Nitzschia sigma</i>	50	III
41	<i>Aulacoseira granulata</i>	100	V
42	<i>Cyclostephanos</i> sp.	42	III
43	<i>Skeletonema</i> sp.	66	IV
44	<i>Thalassiosira pseudonanas</i>	50	III

RFr = Relative Frequency, FrclZ = Frequency class

### **3.2. Description of dominant genera obtained in the study sites**

***Achnanthes* (Bory, 1822)**

**Morphology:** The frustules of *Achnanthes* are heterovalvar. The raphe valve usually possesses a central area of thickened silica, called a fascia. The rapheless valve has no such central area and the sternum may be positioned near the valve margin. In girdle view, the mantle of the rapheless valve appears to be more ornamented than that of the raphe valve. The striae are uni-, bi-, or triseriate and composed of areolae covered by complex cribra, or sieve plates. Cells may grow alone, or may form short chains. Living cells are usually attached to substrata by a mucilage stalk extending through one end of the raphe valve. Most species are found in marine habitats.

**Habitat:** Cosmopolitan.

**Sampling sites:** site 1 to 11, and 16.

**Environmental conditions:** pH =  $6.55 \pm 0.55$  -  $6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34$  -  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  -  $175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75$  -  $6.45 \pm 0.75$  mg/l.

***Achnantheidium* (Kützing, 1844)**

**Morphology:** The genus *Achnantheidium* Kütz has been considered a subgenus of *Achnanthes* by Bory. Round et al. restituted the genus rank to *Achnantheidium* and distinguished *Achnanthes* from *Achnantheidium* based on the areola, raphe, girdle, and plastid characteristics. The species of *Achnantheidium* is generally small; with narrow valves. The genus *Achnantheidium* currently includes freshwater monoraphid species with the following characteristics: (1) linear-lanceolate to lanceolate elliptic cells with length and width less than 30  $\mu\text{m}$  and 5  $\mu\text{m}$ , respectively; (2) concave raphe valve, uniseriate striae, and a wide central area; (3) a well-developed raphe that can be straight or turned to one side; (4) Because of their small sizes and inadequate morphological features.

**Habitat:** Cosmopolitan.

**Sampling sites:** site 1 to 8.

**Environmental conditions:** pH =  $6.55 \pm 0.55$  -  $7.15 \pm 0.30$ , Electrical conductivity =  $198.25 \pm 43.24$  -  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $85.24 \pm 30.45$  -  $175.02 \pm 46.5$  ppm, nitrates =  $5.7 \pm 2.45$  -  $6.45 \pm 0.75$  mg/l.

***Planothidium* (Spaulding et al., 2008)**

**Morphology:** Frustules of *Planothidium* are heterovalvar, with slightly concave raphe and convex raphless valve. Valves are elliptic or lanceolate, with rounded or rostrate apices.

**Habitat:** Epiphytic.

**Sampling sites:** site 1 to 10

**Environmental conditions:** pH =  $6.55 \pm 0.55$  -  $6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34$  -  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  -  $175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75$  -  $6.45 \pm 0.75$  mg/l.

***Caloneis* (Spaulding et al., 2008)**

**Morphology:** Species of *Caloneis* is characterized by chambered striae, like those of *Pinnularia*. The chambered striae give the appearance of one to two longitudinal lines. The striae of *Caloneis* are composed of fine alveoli. Valves are elliptic to linear-elliptic and relatively flat. The raphe valve has a narrow axial area and a small circular or oval central area. The raphe is straight and filiform. Striae are radiate in both raphe and rapheless valves.

**Habitat:** Cosmopolitan.

**Sampling sites:** sites 2, 4 and 16

**Environmental conditions:** pH =  $6.68 \pm 1.35$  -  $7.21 \pm 0.95$ , Electrical conductivity =  $103.23 \pm 86.54$  -  $176.34 \pm 35.54$   $\mu\text{S/cm}$ , Salinity =  $68.23 \pm 54.64$  -  $78.21 \pm 45.55$  ppm, nitrates =  $3.82 \pm 1.13$  -  $4.59 \pm 0.95$  mg/l.

#### ***Cocconeis* (Spaulding et al., 2008)**

**Morphology:** The genus contains both marine and freshwater taxa. Cells possess a single plastid that is flat and C-shaped. Species of *Cocconeis* maybe epiphytic on other algae, as well as on hard substrates (e.g. rock, sand). Valves are elliptic to linear-elliptic and relatively flat. The raphe valve has a narrow axial area and a small circular or oval central area. The raphe is straight and filiform. Striae are radiate in both raphe and rapheless valves.

**Habitat:** Cosmopolitan.

**Sampling sites:** sites 2, 3, 4 and 13

**Environmental conditions:** pH =  $7.15 \pm 0.30$  -  $7.21 \pm 0.95$ , Electrical conductivity =  $176.34 \pm 35.54$  -  $198.25 \pm 43.24$   $\mu\text{S/cm}$ , Salinity =  $78.21 \pm 45.55$  -  $85.24 \pm 30.45$  ppm, nitrates =  $4.59 \pm 0.95$  -  $5.7 \pm 2.45$  mg/l.

#### ***Cymbella* (Spaulding et al., 2008)**

**Morphology:** The valves of *Cymbella* are slightly too strongly asymmetric to the apical axis. Valves are symmetrical to the transapical. The terminal raph fissures are deflected to the dorsal side. Cells slightly too strongly curved dorsiventrally, appearing like an orange slice. Can be colonial, forming branched mucilage stalks or as single cells. One plastid has two H-shaped plates that connect toward the dorsal side of the girdle forming an enlarged bridge.

**Habitat:** Epiphytic.

**Sampling sites:** site 1 to 17.

**Environmental conditions:** pH =  $6.55 \pm 0.55$  -  $6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34$  -  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  -  $175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75$  -  $6.45 \pm 0.75$  mg/l.

#### ***Amphora* (Spaulding et al., 2008)**

**Morphology:** Amphora, valves are semi-elliptic with a smoothly arched dorsal margin and slightly concave ventral margin. An interrupted raphe ledge is present. The striae are interrupted dorsally by intercostal ribs.

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**Habitat:** Epiphytic.

**Sampling site:** site 1.

**Environmental conditions:** pH =  $6.98 \pm 0.68$ , Electrical conductivity =  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $175.02 \pm 46.5$  ppm, nitrates =  $6.45 \pm 0.75$  mg/l.

***Diatoma* (Spaulding et al., 2008)**

**Morphology:** The genus *Diatoma* possesses a raised central sternum, which may not be distinct. Transverse costae are characterically thickened and septae are absent. Striae are comprised of uniseriate rows of areolae. Each valve has a single rimoportula, positioned near a valve terminus and oriented trans-apically.

**Habitat:** Epiphytic.

**Sampling sites:** site 1 to 14

**Environmental conditions:** pH =  $6.55 \pm 0.55 - 6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34 - 227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45 - 175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75 - 6.45 \pm 0.75$  mg/l.

***Epithemia* (Spaulding et al., 2008)**

**Morphology:** *Epithemia* has an eccentric raphe system, positioned along the ventral margin. Each branch of the raphe is arched toward the dorsal margin. Externally, the proximal raphe slits terminate in expanded ends, while internally; the raphe slit is continuous through the central nodule.

**Habitat:** Epiphytic.

**Sampling site:** site 1, 5, 7 and 15.

**Environmental conditions:** pH =  $6.55 \pm 0.55 - 6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34 - 227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45 - 175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75 - 6.45 \pm 0.75$  mg/l.

***Gomphonema* (Pohnert et al., 1996)**

**Morphology:** *Gomphonema* is characterized by; Valves identical, each possessing a raphe (genus is biraphid), smaller than *Gomphoneis*. Valves asymmetric, with one pointed end and the other end bluntly rounded (club-shaped valve), lobed (violin-shaped valve), or pointed (but still slightly asymmetric; may be subtle).

**Habitat:** cosmopolitan.

**Sampling sites:** site 3 to 17

**Environmental conditions:** pH =  $6.55 \pm 0.55 - 7.15 \pm 0.30$ , Electrical conductivity =  $23.6 \pm 20.34 - 198.25 \pm 43.24$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45 - 85.24 \pm 30.45$  ppm, nitrates =  $0.81 \pm 0.75 - 5.7 \pm 2.45$  mg/l.

***Diatomella* (Spaulding et al., 2008)**

**Morphology:** The frustules of *Diatomella* are symmetrical to the apical and transapical axes. The valve outline is linear-elliptical. An internal septum is present, with three openings forming a distinctive internal thickening of silica.

**Habitat:** Cosmopolitan

**Sampling site:** site 1 and 14

**Environmental conditions:** pH =  $6.55 \pm 0.55$  –  $6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34$  –  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  –  $175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75$  –  $6.45 \pm 0.75$  mg/l.

***Pinnularia* (Krammer, 2000)**

**Morphology:** *Pinnularia* is a unicellular, freshwater algae commonly found in ponds and moist soils. It has an elongated, elliptical cell enclosed within silica-impregnated cell walls composed of two overlapping valves. Frustules are ovalvar, isopolar, bilaterally symmetrical. Valve outline usually linear or linear-lanceolate, apices rounded, subrostrate or subcapitate; occasionally with undulate valve margins. Cells can lie in either valve or girdle view

**Habitat:** Cosmopolitan.

**Sampling sites:** site 1 to 17

**Environmental conditions:** pH =  $6.55 \pm 0.55$  -  $6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34$  -  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  -  $175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75$  -  $6.45 \pm 0.75$  mg/l.

***Diploneis* (Spaulding et al., 2008)**

**Morphology:** Frustules of *Diploneis* are typically elliptic to panduriform, with bluntly rounded apices. Each valve possesses two longitudinal canals, one on each side of the raphe. The canals are positioned within the silica cell wall and open to the exterior through pores, but lack openings to the interior of the cell.

**Habitat:** Cosmopolitan.

**Sampling sites:** site 4, 7, 8 and 11.

**Environmental conditions:** pH =  $6.68 \pm 1.35$ , Electrical conductivity =  $103.23 \pm 86.54$   $\mu\text{S/cm}$ , Salinity =  $68.23 \pm 54.64$  ppm, nitrates =  $3.82 \pm 1.13$  mg/l.

***Navicula* (Hasle et al., 1997)**

**Morphology:** *Navicula* is a genus of boat-shaped algae, primarily aquatic, eukaryotic, photosynthetic organisms, ranging in size from a single cell. Defining character of *Navicula* is the lineate areolae, or lineolae. During the mid-1900's, primarily through the work of Hustedt, *Navicula* became a genus that contained a large number of unrelated lanceolate, biraphid species.

**Habitat:** Cosmopolitan.

**Sampling sites:** site 1 to 17.

**Environmental conditions:** pH =  $6.55 \pm 0.55$  -  $6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34$  -  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  -  $175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75$  -  $6.45 \pm 0.75$  mg/l.

***Fragilaria* (Lynbye, 1819)**

**Morphology:** *Fragilaria* is a genus of freshwater and saltwater diatoms. It is usually a colonial diatom, forming filaments of cells mechanically joined by protrusions on the face and in the center of their valves. Frustules are rectangular to lanceolate in girdle view. The pattern of ornamentation on the valve face is variable, but a central sternum is generally present. Frustules are joined by small marginal spines to form ribbon like (band-shaped) colonies. A single rimoportula is present, usually positioned at a distal end. Small, apical porefields are also present. Girdle bands are open. Living cells contain plastids composed of 2 plates, positioned against the valve face.

**Habitat:** Cosmopolitan.

**Sampling sites:** site 1 to 17.

**Environmental conditions:** pH =  $6.55 \pm 0.55$  -  $6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34$  -  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  -  $175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75$  -  $6.45 \pm 0.75$  mg/l.

***Gomphosphaerium* (Kutzing et al., 1836)**

**Morphology:** Unicellular-colonial; colonies microscopic, spherical or irregular, commonly composed of several daughter colonies, free-living (mainly in the metaphyton), usually enveloped by narrow, indistinct, fine and diffuent mucilage.

**Habitat:** Cosmopolitan.

**Sampling sites:** site 5, 13 and 14.

**Environmental conditions:** pH =  $6.55 \pm 0.55$ , Electrical conductivity =  $23.6 \pm 20.34$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  ppm, nitrates =  $0.81 \pm 0.75$  mg/l.

***Melosira* (Baker, 2012)**

**Morphology:** *Melosira* is distinguished from *Aulacoseira* and other freshwater diatoms with similar colonial growth habits by uniformly structured valve walls, without costae or septae, and lack of spines visible under the light microscope. As presently conceived, it has a limited number of freshwater species. This diatom is primarily found in benthic habitats, with cells joined in long filamentous chains. Cylindrical cells with length greater than width. The valves can be either flat or convex. Convex forms can have a small ring of teeth along with a gelatinous cushion in the center of the valve face that helps individual cells form chains.

**Habitat:** Cosmopolitan.

**Sampling sites:** site 1 to 17.

**Environmental conditions:** pH =  $6.55 \pm 0.55$  -  $6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34$  -  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  -  $175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75$  -  $6.45 \pm 0.75$  mg/l.

***Nitzschia* (Mann et al., 2021)**

**Morphology:** In girdle view, the frustule is distinctly sigmoid. In valve view, depending on the position of the specimen, valves may be distinctly sigmoid. Or, valves may also be linear-lanceolate in the middle of the valve, with the ends curved in opposite directions. The apices are small and capitate. Frustules are cylindrical, join face-to-face and form filamentous colonies. Valves are 4-17  $\mu\text{m}$  in diameter, with a mantle height of 4-20  $\mu\text{m}$ .

**Habitat:** Cosmopolitan.

**Sampling sites:** site 1 to 17.

**Environmental conditions:** pH =  $6.55 \pm 0.55$  –  $6.98 \pm 0.68$ , Electrical conductivity =  $23.6 \pm 20.34$  –  $227.5 \pm 45.67$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  –  $175.02 \pm 46.5$  ppm, nitrates =  $0.81 \pm 0.75$  –  $6.45 \pm 0.75$  mg/l.

***Cyclostephanos* (Spaulding et al., 2008)**

**Morphology:** Cells are solitary or in chains. Cells cylindrical in girdle view, mostly circular in valve view. Valves are strongly concentrically undulate. Marginal costae alternate with marginal chambers called areolae. The central areolae of the large specimens are often organized into striae, while the central areolae of smaller specimens are more irregular and scattered.

**Habitat:** Cosmopolitan.

**Sampling sites:** site 5, 7 and 11.

**Environmental conditions:** pH =  $6.55 \pm 0.55$ , Electrical conductivity =  $23.6 \pm 20.34$   $\mu\text{S/cm}$ , Salinity =  $17.32 \pm 15.45$  ppm, nitrates =  $0.81 \pm 0.75$  mg/l.

***Skeletonema* (Horner, 2002) Hasle, 1997**

**Morphology:** *Skeletonema* are cylindrical shaped with a silica frustule. Cells are joined by long marginal processes to form a filament, their length ranges from 2-61 micrometers, with a diameter ranging from 2-21 micrometers.

**Habitat:** Epiphytic.

**Sampling sites:** sites 4, 6 and 8.

**Environmental conditions:** pH =  $6.68 \pm 1.35$ , Electrical conductivity =  $103.23 \pm 86.54$   $\mu\text{S/cm}$ , Salinity =  $68.23 \pm 54.64$  ppm, nitrates =  $3.82 \pm 1.13$  mg/l.

***Thalassiosira* (Spaulding et al., 2008)**

**Morphology:** They can be identified by their characteristic shape: box shaped, cylindrical, drum shaped, discoid, and coin shaped. To a trained microscopist, other readily recognized features such as strutted, occluded, and labiate processes can further distinguish specific *Thalassiosira* species. *Thalassiosira sinica* is similar to *Porosira* species because of the drum-shape cells, the loculate areolae in a radial or fasciculate pattern, no real mantle.

**Habitat:** Cosmopolitan.

**Sampling sites:** sites 1 to 14.

**Environmental conditions:** pH =  $6.68 \pm 1.35$  -  $7.21 \pm 0.95$ , Electrical conductivity =  $103.23 \pm 86.54$  -  $227.5 \pm 45.67$   $\mu\text{S}/\text{cm}$ , Salinity =  $68.23 \pm 54.64$  -  $175.02 \pm 46.5$  ppm, nitrates =  $3.82 \pm 1.13$  -  $6.45 \pm 0.75$  mg/l.

#### 4. Discussion

Environmental parameters in the study sites were divided into 2 categories: Sites 1 to 8 with lowest values and, sites 9 to 17 with highest values. These observations are contrary to those obtained by Safiallah et al. (2020), who showed that physicochemical data did not give large variation among the sites. Based on the majority of the widespread species found in the sites along the river, it can be concluded that the sites showed a slight difference in diatom assemblage from upstream to downstream of the river. Periphytic communities (algae and bacteria) constitute a preferred compartment for long-term monitoring of waterways, due to their specific requirements, varying tolerances to different ranges of water quality parameters. Diatoms represent a majority of the periphyton volume in most aquatic ecosystems and present numerous advantages for bio-indication (Jamileh et al., 2018). According to Rimet (2002), the presence of *Gomphonema parvulum* with abundance above 5% indicates that the sites are probably polluted. In terms of their widely studied ecology, these species are cosmopolitan, tolerant of organic pollution, eutrophication and high nutrient levels. *Melosira varians* is also one of the most common species which grows in benthic habitats of eutrophic streams and lakes (Spaulding et al., 2010). Cantonati et al. (2012) mentioned that the substrate present at a single site might influence the structure of diatom assemblages. Diatom species often show marked preferences for particular substrate and microniches or microhabitats (epilithic, epipelic, epipsammic, epiphytic).

The number of species obtained in the study sites is very few. These are because of the sampling period and effect of environmental conditions like velocity which directly affect the periphyton by uprooting on macrophytes. This is why these species tolerate variations in environmental conditions. These species are mostly cosmopolitan. Too high a current speed detaches species that find themselves trapped in the water column. It has been shown that diatom communities are dominated by a few species that occur frequently and a large number of rare species that occur occasionally or sometimes only once (Jamileh et al., 2018). Raupp et al. (2009) found similar results during their work on the composition of diatoms and their abundance. A diatom community composed by 46 species (3 classes, 10 families and 16 genera) was found. Because waters are acidic (pH 3.32 to 4.52), Eunotiaceae and Pinnulariaceae were represented by the highest number of taxa. The variation of the diatom community is related to the different hydrological periods. They also showed that *Aulacoseira granulata* (Ehr.) Sim var. *angustissima* (Müller) Sim was dominant in the low and rising water periods. Soon-Jin et al. (2011) in the Distribution of benthic diatoms in Korean rivers and streams in relation to environmental variables showed that The genera with most species were *Nitzschia* (34), *Navicula* (19), *Gomphonema* (15), and *Pinnularia* (11) which are characterized as tolerant to  $\alpha$ -mesosaprobic to polysaprobic conditions, and to high nitrogen content. On the same line, Segura-Garcia (2012), observed that the dominant species in the studied locations were *Gomphonema parvulum* (Kützing) Kützing, *Navicula veneta* Kützing, *Nitzschia capitellata* Hustedt. In the same way, Bes et al. (2012) working on composition of the epilithic diatom flora from a subtropical river obtained the same results, showing that the most representative families were Naviculaceae (14 taxa), Gomphonemataceae (10) and Bacillariaceae (10). The genera richest in species were *Gomphonema* Ehrenberg, *Navicula* Bory, *Eunotia* Ehrenberg and *Nitzschia* Hassal. Contrary to their works, *Navicula* and *Nitzschia* were very few and/or absent because of the velocity of the water very high in the sampling rivers. Another explanation would come to Safiallah et al.

**Commented [n4]:** limnological parameters instead of environmental parameters

(2020) who observed that very few species present in the Kashkan River preferred only one substrate and appeared as epipellic or epilithic taxa; yet *Navicula* is more cosmopolitan. Other studies from different rivers indicated that benthic diatoms in lightly or highly polluted rivers have similar dominant species, from which the most frequent are *Planothidium lanceolatum*, *Cocconeis placentula*, *Navicula lanceolata*, *N. gregaria*, *N. tripunctata*, and *Nitzschia palea* (Noga et al., 2014).

#### 4. CONCLUSION

The general objective was to characterize benthic diatoms in Nkwen Rivers (Bamenda, Cameroon). All measured physicochemical parameters varied significantly from one site to another. The inventory of diatoms has made it possible to identify a total of 44 abundant and dominant species and 22 genera from the benthic diatom communities. Majority of genera were cosmopolitan and tolerated high level of salinity and nitrates. The description and informations obtained on the different genera can be an aid in creating reference database on diatoms for their utilization in ecological assessment.

#### DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that no generative AI technologies such as large language models (chatgpt, copilot, etc) and text-to-image generators have been used during writing or editing of this manuscript.

#### REFERENCES

- Armbrust, E. V. (2009). The life of diatoms in the world's oceans. *Nature*. 459: 185-192.
- Beraldi-Campesi, H., Arenas-Abad, C., Auque-Sanz, L., Vázquez-Urbez, M. & Pardo-Tirapu, G. (2016). Benthic diatoms on fluvial tufas of the Mesa River, Iberian Range, Spain. *Hidrobiológica*, 26(2), 283-297.
- Bes, D., Ector, L., Torgan, L. C. & Lobo, E. A. (2012). Composition of the epilithic diatom flora from a subtropical river, Southern Brazil. *IHERINGIA, Sér. Bot., Porto Alegre*, 67(1), 93-125.
- Camerlo, R. T., Grethe, R. H., Karen, A. S., Karl, T., John, T. & Berit, R. H. (1997). Identifying marine phytoplankton. Academic press (Ed.), San Diego, California, USA.
- Cantonati, M., Angeli, N., Bertuzzi, E., Spitale, D. & Lange-Bertalot, H. (2012). Diatoms in: springs of the Alps: spring types, environmental determinants and substratum. *Freshw Sci.*, 31, 499-524.
- Field, C. B., Behrenfeld, M. J., Randerson, J. T. & Falkowski, P. G. (1998). Primary production of the biosphere: Integrating terrestrial and oceanic components. *Science*, 80(281), 237-240. <https://doi.org/10.1126/science.281.5374.237>.
- Guiry, M. D. & Guiry, G. M. (2024). AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. <https://www.algaebase.org>. (Accessed on 18/12/2024).
- Jamileh, P. M., Taher, N., Zohreh, R., Javid, I. N. & Younes, A. (2018). The epilithic and epipellic diatom flora of the Balikhli River, Northwest Iran. *Turk J Bot.*, 42, 518-532. <https://doi.org/10.3906/bot-1711-46>.
- Krammer, K. & Lange-Bertalot, H. (1986). Bacillariophyceae. 1 Teil: Naviculaceae. In: Ettl, H., Gerloff, J., Heynig, H. and Mollenhauer, D. (Eds, pp. 2-15), Süßwasser- flora von Mitteleuropa, 876 Stuttgart, New York: Gustav Fischer Verlag.
- Mann, D. G. & Vanormelingen, P. (2013). An inordinate fondness? the number, distributions, and origins of diatom species. *J Eukaryot Microbiol.*, 60, 414-420. <https://doi.org/10.1111/jeu.12047>.

**Commented [n5]:** Diversity index, anova and recent statistical tools should use in study specially when u r doing work on species diversity and correlation is lacking between species diversity and limnological parameters.

- Ndikebeng, K. R., Forba, C. F., Tume, S. J. P., Yenlajai, B. J. F. & Kimengsi, J. N. (2023). Land cover dynamics and implications on water resources in Bamenda III Sub-Division, North-west Region, Cameroon. *International Journal of Global Sustainability*, 7(1), 37-52.
- Neba, A. S. (1999). Morden Geography of republic of Cameroon. Neba publisher (Ed.), Bamenda Cameroon.
- Noga, T., Kochman, N., Peszek, L., Stanek-Tarkowska, J. & Pajaczek, A. (2014). Diatoms (Bacillariophyceae) in rivers and streams and on cultivated soils of the Podkarpacie region in the years 2007-2011. *Journal of Ecological Engineering*, 15, 6-25.
- Nyambod, E. M. (2010). Environmental Consequences of Rapid Urbanisation: Bamenda City, Cameroon. *Journal of Environmental Protection*, 1, 15-23. <https://doi.org/10.4236/jep.2010.11003>.
- OFEV. (2007). Méthodes d'analyse et d'appréciation des cours d'eau : donnée Niveau R (Région). FOEN (Ed.), Report, Switzerland.
- Raupp, S. V., Torgan, L. & Melo, S. (2009). Planktonic diatom composition and abundance in the Amazonian floodplain Cutiaú Lake are driven by the flood pulse. *Acta Limnol. Bras.*, 21(2), 227-234.
- Rimet, F. (20012). Recent views on river pollution and diatoms. *Hydrobiologia*, 683, 1-24.
- Safiallah, H., Saadatmand, S., Kheiri, S. & Iranbakhsh, A. (2020). Biodiversity of diatoms in the Kashkan river in the Zagros mountains, western Iran. *Iran. J. Bot.*, 26(2), 141-161. <https://doi.org/10.22092/ijb.2020.351698.1296>.
- Segura-García, V., Cantoral-Uriza, E. A., Israde, I. & Maidana, N. (2012). Epilithic diatoms (Bacillariophyceae) as indicators of water quality in the Upper Lerma River, Mexico. *Hidrobiológica*, 22(1), 16-27.
- Shibabaw, T., Beyene, A., Awoke, A., Tirfie, M., Azage, M., Triest, L. (2021). Diatom community structure in relation to environmental factors in human influenced rivers and streams in tropical Africa. *PLoS ONE*, 16(2), e0246043. <https://doi.org/10.1371/journal.pone.0246043>.
- Soon-Jin, H., Nan-Young, K., Sung Ae, Y., Baik-Ho, K., Myung Hwan, P., Kyung-A.Y., Hak, Y. L., Han, S. K., Yong, J. K., Jungho, L., Ok Min, L., Jae, K. S., Eun, J. L. & Sook, L. J. (2011). Distribution of benthic diatoms in Korean rivers and streams in relation to environmental variables. *Ann. Limnol. - Int. J. Lim.*, 47, 15-33. [doi.org/10.1051/limn/2011017](https://doi.org/10.1051/limn/2011017).
- Spaulding, S. A., Lubinski, D. J. & Potapova, M. (2010). Diatoms of the United States. Boulder, CO, USA: University of Colorado. <https://westerndiatoms.colorado.edu>.
- Tita, M. A., Kuitcha, D., Magha, A. & Ndjama, J. (2012). Occurrence of macrophytes in the Mezam river system in Bamenda (Cameroon) and their role in nutrient retention. *Syllabus Review Sci. Ser.*, 3, 1-10.
- Trembley, R. (2015). Elaboration of a method based on Diatoms for evaluating the ecological integrity of Temperate lakes of Québec. PhD Thesis, University of Laval, Québec, Canada.
- Vélez-Agudelo, C. & Espinosa, M. A. (2021). Distribution and environmental preferences of diatoms along the Negro River, Patagonia, Argentina. *Limnetica*, 40(2), 247-265.